SOME FACTORS AFFECTING THE DEVELOPMENT OF MUD-CRACKS[1]

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INTRODUCTION

Casual examination of the apparently erratic lines known variously as mud-cracks, sun-cracks, and shrinkage-cracks affords little promise of results of interest from their systematic study. The great geologic interest which these products of desiccation possess in connection with the history of formations in which they occur should nevertheless encourage the geologist to ascertain what effect variation in the conditions under which they are formed will have on the resulting kind or type of mud-crack. With the object of ascertaining the nature and extent of the modification of the type of mud-crack which may result from varying the conditions of its formation, I have carried out the laboratory experiments described below. These have been planned with a view to discovering (*a*) the relative effects of rapid and slow desiccation on the same mixture, (*b*) what influence, if any, composition of the mud has upon the mud-cracks, (*c*) the possibility of producing parallel mud-cracks, and (*d*) the differences which distinguish saline from fresh-water mud-cracks.

EXPERIMENTS

Two kinds of clay have been used. In experiments 1 and 3 a mud was used which came from the bottom of Lake Ontario, at a depth of 630 feet, and represented very fine-textured material. The other experiments were made with blue marine clay of Pleistocene age from the Ottawa valley near Ottawa. This is also a very fine-textured and tenacious clay.

Experiment 1.—Lake clay which was thoroughly mixed with about 5 times its volume of fresh water was poured into two

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porcelain vessels of the same shape and size, each being completely filled. One of these was set in direct sunlight when the daily noon temperature exceeded 100°, and the other was kept in the shade until the water had evaporated and mud-cracks had developed. The specimen exposed to sunlight developed mud-cracks on the third day. The other vessel showed the first mud-cracks on the eighth day. When completely dried, the mud in the two vessels showed a very marked difference in the size and number of polygons outlined by the mud-cracks developed. The sun-dried mud had cracked into 6 irregular-sided polygons, while the same volume of mud, which had been slowly dried in the shade during a period about three times that given the direct sunlight specimen, showed 26 polygons. Rapid drying thus seems to produce comparatively widely spaced mud-cracks, while slow desiccation gives closely spaced mud-cracks. Some interesting incidental observations were made in connection with this experiment on the tendency displayed by the very fine sand grains to segregate themselves from the mass of the mud and to gather along the edges of the joints and the margin of the vessels holding the mixtures. This segregation of the sand grains resulted in a ring of sand around the outer margin of the mud where it came in contact with the sides of the vessel. Along the sides of many of the mud-cracks the upper angle of the polygon was edged by a continuous border of sand. On the lower side of the polygon edges the sand showed no tendency to segregate. This segregation of the sand along the edges of the mud-cracks appeared to be dependent in part upon the extreme fineness of the grains. An attempt to repeat this phase of the experiment by adding sand of average fineness to mud which was desiccated in the sun failed to show any segregation phenomena, presumably because of the larger size of the sand grains used.

Experiment 2.—This experiment was designed to show what effect variation in the composition of the mud used would have on the character of the mud-cracks. Three parallel experiments were carried out for this purpose. The fine-textured blue clay of Pleistocene age from the Ottawa Valley was used. A mixture of this clay with 3 quarts of water was divided into three equal parts. To one of these (3*a*) was added 2 ounces of fine sand. The same

amount of powdered marl was added to the second (2*b*), while the third lot was left a clay and water mixture (2*c*). These three mixtures, representing sandy mud, marly mud, and clay mud, were placed in three shallow pans for desiccation in the sun. The resulting mud-cracks show that the clay mud (2*c*) cracked into much larger polygons (Fig. 1) than either the sandy or marly mud (Fig. 2). The sandy mud (3*a*) developed more than three times as many

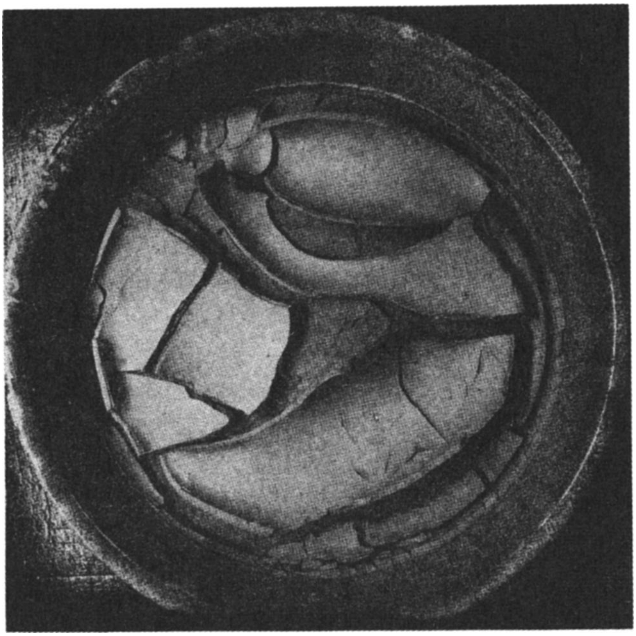

FIG. 1.—Normal fresh-water mud-cracks in blue-clay mud. ¼ natural size

polygons (Fig. 3) as the clay mud, while the marly mud showed more than twice as many polygons as the clay mixture. The large number and very angular course of many of the mud-cracks in the sandy mixture are characteristic features which distinguish this mixture from either of the other two.

Experiment 3.—A portion of the same clay mixture used in experiment 1 was placed in a shallow pan 11 inches in diameter. The water was allowed to evaporate slowly without exposure to

the sun. One side of the pan was raised $\frac{1}{10}$ inch higher than the opposite side, so that near the end of evaporation the lower side remained moist after the upper side had become quite dry, the object being to see what effect, if any, this drying out of the mud in a lateral direction would have on the character of the mud-cracks. The result of this experiment is shown in the photograph (Fig. 4), which was made before the lower margin had entirely dried, the moist portion being indicated by the darker part near the base of the picture. Instead of the usual reticulated mud-crack lines, most of the mud split up into a set of ribbon-like strips averaging $\frac{1}{2}$ inch in width and having a length of 3 to 6 inches. The direction of the mud-cracks which gave this ribbon-like effect was transverse to, and evidently controlled by, the zone separating the completely dried from the

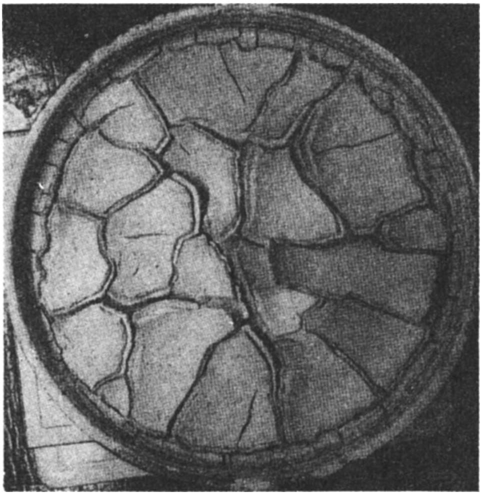

FIG. 2.—Mud-cracks in mud composed of clay and marl. $\frac{1}{4}$ natural size.

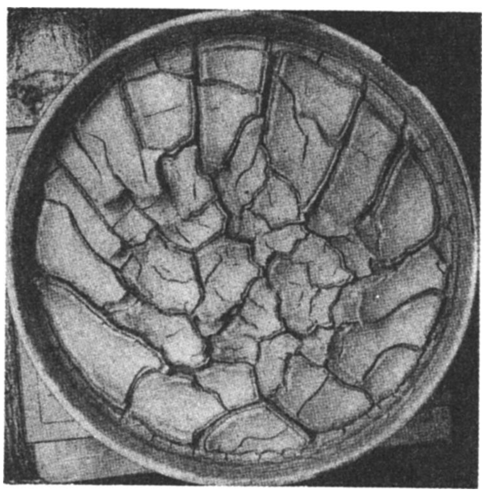

FIG. 3.—Mud-cracks in sandy mud. $\frac{1}{4}$ natural size.

partially dried mud (see Fig. 4). The cracks developed with the retreat of this zone away from the area which first dried. In a small patch of this first dried section no mud-cracks formed. This experiment shows that approximately parallel mud-cracks may be developed by differential desiccation, and affords a clue to the cause of certain kinds of joints which appear to be definable as parallel mud-cracks of considerable vertical extent.

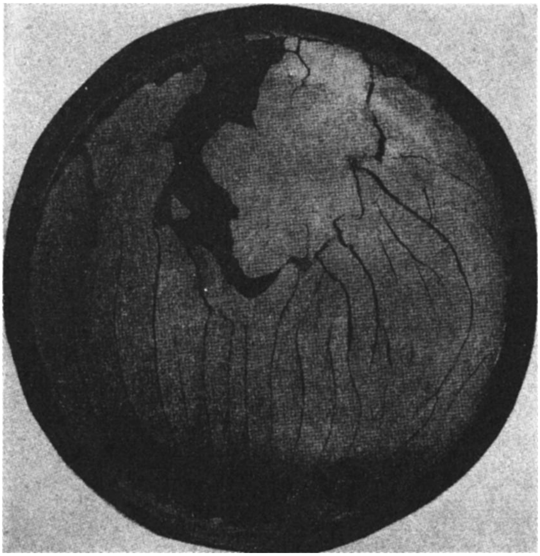

FIG. 4.—Mud-cracks cutting the mud into ribbon-like strips. $\frac{1}{4}$ natural size

Experiment 4.—A 2-quart mixture of blue clay and water was divided into two equal parts. A tablespoonful of salt was added to one of these, and the other was left fresh. The two mixtures were placed in shallow pans $9\frac{1}{2}$ inches in diameter and put in the sun for evaporation and desiccation. Complete drying or desiccation of the salt-water pan was finished on the eighth day after starting this experiment. The first noted difference between the two pans was the earlier drying out of the saline mixture. All the liquid water had left the salt-water mixture at least a day before the fresh-water mud had ceased to be a semi-liquid mass. The desiccation was finished in a temperature of 110°.

In the fresh-water mixture preliminary mud-cracks developed on a dried-surface layer of the thickness of paper two days before the mixture underneath had lost its semi-liquid character. The earlier drying out of this surface layer of paper-like thinness retarded the drying of the lower layers and led to the excessive curling of the polygons as they were cut out by the developing mud-cracks. A lot of closely curled pieces of sediment resembling shavings repre-

FIG. 5.—Desiccated fresh-water mud. ¼ natural size

sented the final stage of the mud-crack development in the fresh-water mixture (see Fig. 5). An interesting feature of this experiment is the difference in color exhibited by the thin uppermost layer, which had been directly exposed to the air and sun, and the sediment below. The topmost film had a lead-gray color, while the sediment below it showed a creamy-white color in no way resembling the original blue clay. The general character of the mud-cracks shown by this pan corresponds closely to those most commonly met with in nature except in the extreme curling of the polygons.

The behavior of the saline mixture was markedly different from that of the fresh-water one. Except for a crack extending round

the margin of the pan and separating the mud adhering to the side from that on the bottom no regular mud-cracks developed until a very late stage of the desiccation. Instead of the usual familiar, somewhat erratic, mud-crack lines seen on drying mud, a five-rayed star-shaped figure (see upper right-hand quarter of Fig. 6) cutting to the bottom of the sediment first appeared. A day later two other figures developed, each having three lines of equal length and form-

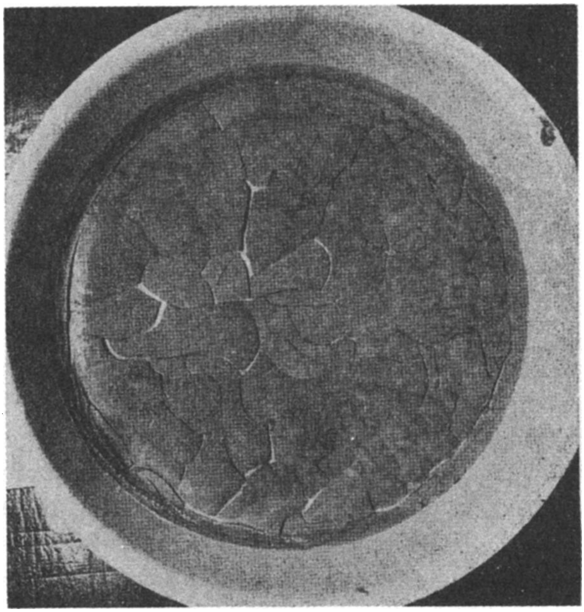

FIG. 6.—Desiccated saline mud. The same quantity and kind of mud was used as in Fig. 5 except that salt was added. Note that margins of polygons are curved downward instead of upward as in the fresh-water mud-cracks shown in Figs. 1, 2, 3, and 5. $\frac{1}{4}$ natural size.

ing at their junction angles of 120°. Simultaneously with the development of the three-line figures the entire surface became marked by small hexagonal polygons with a diameter ranging from $\frac{1}{8}$ inch to $\frac{1}{16}$ inch and giving it a honeycomb appearance. These may be seen indistinctly on the left half of Fig. 6. These were not sharply defined nor marked off by mud-crack fissures, but were discernible through a slightly lighter color of the sediment along the bounding lines, and in some cases by a slight deliquescence of

salt along these lines. These small polygons appear to represent the convection cells of Benard,[1] Dauzére,[2] and Sosman,[3] and have no direct relationship to mud-cracks. A few hours after the appearance of the triradiate figures some regular mud-cracks formed in the median portion of the pan, cutting a limited area into rather small polygons. Two of these mud-cracks were extensions of arms of the three-line figures previously mentioned. Two days after the desiccation appeared to have been completed, the remainder of the surface cracked, after being removed from the sun, splitting the entire surface into polygons. A noteworthy feature of these polygons is downwarping of their margins and absence of lateral shrinkage, which is in sharp contrast with the upwarping of the sides and considerable shrinkage of polygons which formed from the fresh-water mud. In fact, the saline mud showed as a whole slight lateral expansion which was taken up by the arching upward of the median portions of the polygons.

Considered from the standpoint of preservation as permanent features in the strata of consolidated rocks, mud-cracks in saline clays would have a rather poor chance of permanent preservation owing to their slight breadth. If preserved, they would be quite inconspicuous as compared with ordinary mud-cracks. The star-shaped figures, however, by reason of their broad and deeply incised arms lend themselves well to preservation under natural conditions of sedimentation and should be regarded, when found on rock surfaces, as evidence of subaërial desiccation. This experiment represents the behavior of highly saline mud such as would be found on the shores of salt lakes or detached arms of the sea rather than that of the muds ordinarily met with about the estuaries of rivers, which have a much lower degree of salinity.

The salinity of ordinary estuarine mud was approximated in another experiment. Sea water was used in still another. In all these supplementary experiments, including a sample of mud having less than the salinity of ordinary tide-flat mud, desiccation produced

[1] H. Benard, *Les Tourbillons cellulaires dans une nappe liquide*, etc., thesis, Paris, 1901; *Rev. gen. Sci.*, XI (1900), 1261–71, 1309–38.

[2] C. Dauzére, *Jour. physique*, VI (1907), 892–99; VII (1908), 930–34; *Assn. franc. av. sci.*, 1908, pp. 289–96.

[3] Robert B. Sosman, "Types of Prismatic Structure in Igneous Rocks," *Jour. Geol.*, XXIV (1916), 219–24.

polygons in which the upper and lower surfaces were perfectly flat, the edges showing no inclination either to warp up or down.

SUMMARY AND DISCUSSION

The experiments described above justify the following deductions: Rapid desiccation produces mud-cracks which are more widely spaced than those produced by slow desiccation. In mud-cracks occurring in rocks of the same or similar composition the relative size of the resulting polygons would therefore serve as a basis for inferring the relative temperatures under which they were formed.

The composition and the resulting tenacity of the mud very materially affects the spacing of the mud-cracks. The presence of marly material or the addition of sand gives polygons which are much smaller than those formed in clay mud (Figs. 1–3). In the case of sandy mud a sufficient excess of sand entirely prevents the formation of mud-cracks. Hence a bed of sand might be exposed to subaërial conditions without furnishing mud-crack evidence of the fact. Temperature and tenacity of the material are two primary factors in controlling the spacing of mud-cracks.

Approximate parallelism of mud-cracks may result from zonal drying of the mud. The parallelism seen in many systems of joint structure may thus be duplicated under special conditions in shrinkage-cracks in mud.

A high degree of salinity delays the formation of mud-cracks and results in polygons in which the margins are inclined downward (Fig. 6). These are in marked contrast to the polygons formed in fresh-water mud, which dish upward, saucer-like (Figs. 1, 2, 3, and 5). The polygons formed in mud with the salinity of ordinary sea water warp neither upward nor downward at the margins, but retain a flat surface. It should be pointed out here that the marked differences observed in the experiments between the behavior of fresh-water, highly saline, and moderately saline muds are not ordinarily so well marked in nature as the accompanying illustrations might lead the reader to expect. The strong tendency, as shown by the pan experiments, of fresh-water mud to warp upward and of very saline mud to warp downward at the margins of the polygons on cracking is modified and often neutralized by

the tenacity of the mud, which on a mud flat may prevent the topmost cracked layers from partially splitting away from the subjacent layers, as they must do if this warping occurs. Clearly the cohesion between the layers of mud is greater than that between the smooth bottom of the pan and the mud in it. Observation of sun-cracked fresh-water mud on the bottom of evanescent ponds will show that the polygons warp upward or remain flat, according to the tenacity of the mud. Where the tenacity of the mud is slight, the saucer-shaped polygons are dominant.

In the case of fossil mud-cracks the geologist can make definite deductions regarding the salinity of the original mud only where there has been distinct upwarping or downwarping of the polygons. Where the surface is flat, as is usually the case, lack of warping is as likely to be due to the tenacity of the mud overcoming the warping influence of fresh water as to the normal influence of the salinity of sea water. Where the polygons show a definite saucer-like upwarp at the margins, however, the inference that they were formed from fresh-water mud would be inevitable. I have described[1] from bed A of the Mount Wissick section in New Brunswick an example of this kind which in the light of these experiments must be referred to continental or fresh-water conditions, although I originally supposed it to have been formed on a tidal flat.

Fossil examples of the inverted-saucer type of polygon due to the drying of very saline muds are apparently not very common. Some peculiar structures in Silurian dolomite described by Gilbert[2] and illustrated[3] by Kindle probably represent a phase of this phenomenon. These curved plates in the Lockport dolomite near Niagara Falls, which are probably the result of the desiccation of highly saline sediments, were supposed by Hall to be of concretionary origin. They immediately precede in the section a rock series in which beds of gypsum and rock salt afford conclusive evidence of the highly saline character of the sediments deposited a little later.

[1] *Geol. Surv., Can. Mus. Bull. 2*, 1914, p. 37.

[2] "Undulations of Certain Layers of the Lockport Limestone" (Abstract), *Science*, N.S., XXI (1905), 224.

[3] *U.S. Geol. Surv. Folio No. 190*, 1914, p. 59, Pl. 24.